Searching for red worlds

The SPECULOOS project aims to detect terrestrial exoplanets well-suited for detailed atmospheric characterization, explains Principal Investigator **Michaël Gillon.**

Studying alien worlds circling other stars than the Sun is no more science-fiction. Within the last 15 years, first observational constraints have been gathered on the atmospheric properties of some giant exoplanets in orbit around bright nearby stars[1]. Extending these pioneering studies to smaller and more temperate exoplanets holds the promise of revolutionizing our understanding of rocky planets by enabling us to assess their diversity at the galactic scale, not only in terms of orbits, but also in terms of atmospheric compositions, surface conditions, and, eventually, habitability. A promising shortcut to this revolution consists in the detection of temperate rocky planets transiting hosts small, cool, and nearby enough to make possible their detailed atmospheric characterization - including the detection of potential biosignatures - by eclipse spectroscopy with the James Webb Space Telescope (JWST) and other upcoming facilities[2].

SPECULOOS (Search for habitable Planets EClipsing ULtra-cOOl Stars) aims to seize this opportunity by exploring for transits the nearest "ultracool dwarf"[3] stars. With masses ranging from 7 to 10% the one of the Sun, these Jupiter-sized stars are located at the extreme bottom of the main-sequence. Their luminosities are less than 0.1% the one of the Sun, which makes their habitable zones correspond to orbits of a few days only, maximizing the transit probability and frequency of a putative temperate planet. Their Jupiter-like sizes translate into transit depths of ~1% for an Earth-sized planet, within reach of ground-based telescopes. The combination of their small sizes, masses, and temperatures maximizes the potential for the atmospheric characterization of a transiting temperate Earth-sized planet with JWST.

The basic concept of SPECULOOS is to search for transits the ~1000 ultracool dwarf stars that are bright enough in the near-infrared to make possible the atmospheric characterization of an Earth-sized planet with JWST. It uses for this purpose ground-based 1m-class robotic telescopes equipped with highly sensitive CCD cameras that monitor individually each of its 1000 targets. The mean monitoring duration per target is ~19 nights, and is fine-tuned as a function of each target spectral type so to reach a probability of 70% to observe the transit of a planet receiving from its host star the same irradiation than the Earth from the Sun. For a given night, each SPECULOOS telescope observes continuously the same target, so to maximize its capacity to detect a low-amplitude transit.

SPECULOOS will eventually be based on two nodes, one in both hemispheres. The southern one, the SPECULOOS Southern Observatory (SSO) is currently being commissioned at the ESO Paranal Observatory in the Chilean Atacama Desert (Fig). It consists of four 1m telescopes that will explore for transits ~500 southern ultracool dwarf stars. This exploration should take ~7 years. The northern node of SPECULOOS, the SPECULOOS Northern Observatory (SNO), is planned to consist also of four 1m telescopes, and it will be located at Teide Observatory in Tenerife (Canary Islands). Its first telescope will be installed at the end of 2018, and the full observatory is planned to be operational for early 2020.

The SPECULOOS Southern Observatory at Paranal. Credit: M. Gillon

SAINT-Ex, a new robotic 1m telescope being installed at San Pedro Mártir Observatory (Mexico) will also partially contribute to SPECULOOS. Finally, two 60cm robotic telescopes, TRAPPIST-South (La Silla Observatory, Chile) and TRAPPIST-North (Oukaïmeden Observatory, Morocco), participate also to SPECULOOS, focusing on its ~100 brightest targets. In fact, SPECULOOS started back in 2011 as a prototype mini-survey on TRAPPIST-South with a target list composed of the 50 brightest southern ultracool dwarf stars. The goal of this prototype was to assess the feasibility of SPECULOOS, but it did much better than that. Indeed, it detected around one of its targets an amazing planetary system, TRAPPIST-1, composed of seven Earth-sized planets in temperate orbits of 1.5 to 19 days[4,5]. At least three of these planets orbit within the habitable zone of the star, and all of them are particularly well-suited for a detailed atmospheric study with JWST[6]. Thanks to the resonant[7] and transiting configuration of the system, the masses and radii of the planets could be very precisely measured [8,9]. The resulting densities suggest for most planets rocky compositions with a volatile content significantly larger than Earth's.

The detection of TRAPPIST-1 out of a target list of only 50 objects, and the apparent low densities of most of its planets, suggest that compact systems of water-rich rocky planets could be very frequent around ultracool dwarf stars, in agreement with recent theoretical predictions[10]. If this is the case, then SPECULOOS should find many other TRAPPIST-1-like systems, to eventually produce a catalog of several dozen temperate rocky planets well-suited for detailed atmospheric characterization with next-generation major astronomical facilities.

SPECULOOS is a project led by the University of Liege (Belgium) and done in collaboration with the Universities of Cambridge, Jeddah, MIT, Berne, Birmingham, California San Diego, Cadi Ayyad, and the Astrophysics Institute of the Canaries. It is mostly funded by the European Research Council and several private sponsors and foundations (Simons, Heising-Simons).

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[1] Crossfield 2015, *Publications of the Astronomical Society of the Pacific*, 127, 941
[2] Kaltenegger & Traub 2009, *The Astrophysical Journal*, 698, 519
[3] Kirkpatrick 2005, *Annual Review of Astronomy and Astrophysics*, 43, 195
[4] Gillon et al. 2016, *Nature*, 533, 221
[5] Gillon et al. 2017, *Nature*, 542, 456
[6] Morley et al. 2017, *The Astrophysical Journal*, 850, 121
[7] Luger et al. 2018, *Nature Astronomy* , 1, 129
[8] Grimm et al. 2018, *Astronomy & Astrophysics*, in press, arXiv:1802.01377
[9] Delrez et al. 2018, *Monthly Notices of the Royal Astronomical Society*, 455, 3577
[10] Alibert & Benz, 2017, *Astronomy & Astrophysics* , 598, 5